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Process Automation versus Power System Automation

Author: Anannya Mukherjee

Abstract: Industrial Automation is one of the areas of engineering which has been undergoing continuous and fast developments since its inception. Great achievements have been realized in the last two decades in this field but the technology is still under development. Based on the control variables, industrial automation can broadly be divided into two categories, such as Process Automation and Power System Automation. Difference in the nature of control variables between process and power systems have resulted in difference in the philosophy of control, protection and monitoring, between these two systems. The main objective of this article is to discuss and analyze if these differences have any impact on the automation system. Dedicated and separate automation systems for process and power systems are being installed in the plants. The paper will discuss if it is possible to combine both the systems and have a common automation system for controlling and monitoring of the process and power systems, which may lead to much desirable reduction in investment cost and better utilization of manpower. This paper also provides a survey of the major achievements, ongoing developments and the future expectations and challenges in process automation and power system automation.

Index Terms: DCS: Distributed Control Systems, IEDs: Intelligent Electronic Devices, I/O: input/output, LAN: Local Area Network, MTU: Master Terminal Unit, PLC: Programmable Logic Controllers, PMS: Power Management System, RTU: Remote Telemetry Units, SCADA: Supervisory Control and Data Acquisition, SCS: Substation Control Systems, UPS: Uninterrupted Power Supply.

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1. INTRODUCTION:

Automation is the use of machines, control systems and information technologies to optimize productivity in the production of goods and delivery of services. Automation reduces operation time cycle and provides high degree of accuracy in control. Automation replaces human operators in tasks that involve hard physical work and monotonous and repetitive activities. Automation also helps performing tasks that are beyond human capabilities i.e. working in an unusual condition and dangerous environment.

Automation varies with respect to purposes and requirements within a manufacturing structure. In this paper, we examine *Process Automation* and *Power System Automation*. Difference between process and power systems in terms of nature, composition, and parameters have resulted in difference in the philosophy of control, protection and monitoring between these two systems. By delineating these differences, we aim to ascertain whether these differences have any impact on the operation and design of whole automation structure for a manufacturing unit. The key research questions are: why do we often use two different systems for automation of process and power systems in a plant? Is it possible to combine both the systems and have a common automation system for controlling and monitoring of the process and electrical variables, which could result in less investment cost and reduced manpower? Given the enormity of the need to automate systems across industries, answers to these questions have important implications for future design of automation schemes.

A process is broadly defined as an operation which transforms inputs into outputs. During the process, the raw materials are transferred, measured, mixed, heated, cooled, filtered, stored, or handled in some other way to produce the end product. Process Automation being discussed in this article refers to the automatic control and monitoring of process variables, such as pressure, flow, temperature, level etc, of the process plants which are mainly used in the chemical industry, oil and gas industry, food and beverage industry, pharmaceutical industry, water treatment industry etc.

A pertinent question is: Why control and monitoring of process variables are required? Process control refers to the methods that are used to control process variables during the manufacturing process. Factors such as the proportion of ingredients in a mixture, temperature, pressure, flow etc. to be maintained during the process can significantly impact the quality of an end product. All process systems consist of three main factors: the manipulated variables, disturbances, and the controlled variables. Typical manipulated variables are valve position, motor speed, damper position, or blade pitch. The controlled variables are those conditions such as temperature, level, position, pressure, pH, density, moisture

- *Miss Anannya Mukherjee student of Bachelor's degree program in Electronics and Communication Engineering, ,at the Institute of Engineering and Management, Kolkata, India.*
  E-mail: anannyamukherjee1@gmail.com

content, weight, and speed—that must be maintained at some desired value. For each controlled variable there is an associated manipulated variable. The control system must adjust the manipulated variables so the desired value or "set point" of the controlled variable is maintained despite any disturbances. Disturbances enter or affect the process and tend to drive the controlled variables away from their desired value or set point condition. Typical disturbances include changes in ambient temperature, in demand for product, or in the supply of feed material. The control system must adjust the manipulated variable so the set point value of the controlled variable is maintained regardless of the disturbances. If the set point is changed, the manipulated quantity must be altered to adjust the controlled variable to its new desired value. Process automation technology is the tool that enables manufacturers to keep their operations running automatically and unperturbed within the set limits of the process and also to ensure quality and safety.

On the other hand, Power System as a whole refers to generation, transmission and distribution networks. Power systems comprises of generating units (that produce electricity), high voltage transmission lines (that transport electricity over long distances), distribution lines (that deliver the electricity to consumers), substations (that connect the generation, transmission and distribution with each other) and energy control centers (that coordinate the operation of the components). Power System Automation allows automatic control and monitoring of the electrical parameters such as power flow, voltage, current etc.

Both process automation and power system automation have seen vast technological improvements since 1990s but the automation technology is still under development. What are the major challenges in the automation field? What are our expectations from the industrial automation in future?

The following sections of this article provide a survey and technical analysis of the above-mentioned issues and look for the answers to the research questions.

2. Comparing the Process Automation with Power system Automation:

It is very important to understand the difference in philosophy of control & monitoring between process system and power system, before comparing the automation systems for both.

2.1 Differences in Philosophy of Control and Monitoring:

Control loops in the process industry requires three tasks to occur, these are Measurement, Evaluation and Adjustment. Many different type of instruments and devices are used in control loops (e.g. sensors, transmitters, actuators). Measurement is performed by the sensors & transmitters and Adjustment is done by the actuators (see the following sections for details). Under the Evaluation step, the measurement value is examined, compared with the desired value or set point, and the amount of corrective action needed to maintain proper control is deter-mined. Evaluation is done by the controllers which can be the PLC, DCS, fieldbus controller or it can also be done by a Central host computer control system.

Electrical Network Automation system is divided into the following two main categories.

- Power Generation Control/Power Management systems.
- Electrical Substation Automation System.

Power Generation Control: Modern power plants with their own turbine generators are equipped with electrical automation system often known as a computer based power management system (PMS). The main purpose of this system is to optimise the power generation with most economic fuel consumption. The power system is the 'life-blood' of the whole plant and therefore it must have high availability and high reliability. Main functions of Power generation control are Active and Reactive Power control, Auto-synchronising and load sharing among Generators and Operational set point control for Generators.

Power generation control can be considered as similar to the process control where Measurement, Evaluation and Adjustment are performed.

Electrical Substation Automation System: Substations are key components of the power grid, facilitating the efficient transmission and distribution of electricity. They play a vital role in terms of monitoring and controlling power flows and provide the interconnection between generating facilities, transmission and distribution networks and end-consumers. Substations typically have transformers, switching, protection and control equipment. Switchgears/circuit breakers are used for switching operations as well as to interrupting any short circuits or overloads that may occur on the electrical network under abnormal conditions. Other devices such as power capacitors, UPS and voltage regulators are also often located in a substation. Substation automation systems make the control and monitoring of the electrical equipment possible in real time and help maximize availability, efficiency, reliability, safety and data integration. Main functions of Electrical Substation Automation System are the following.

a. Power flow measurement and analysis
b. Energy demand control
c. Transformer load management.
d. Operational planning.
e. Energy scheduling.

Typical control requirement of Transmission and

Distribution network is different from that of Process systems. Measurement, Evaluation and Adjustments sequence and functions are not followed. For transmission and distribution network, electrical control is mainly limited to closing and opening of the circuit breakers and switches as desired by the operator, under normal operating condition. Operator can control the electrical system from SCS or from the central host computer control system.

2.2 Differences in Automation Architecture.

Architecture of typical Process Automation and Power System Automation are shown in Figure-1 and Figure-2 respectively. The main components of automation systems are discussed below:

2.2.1 Sensors and Transmitters:

It is true that we can control what we can measure. Hence it is very important to measure various parameters such as temperature, pressure, flow, chemical concentration, electric current, voltage etc for controlling them. Large industrial plants have thousands of sensors to ensure accurate measurement of parameters for monitoring and control. For certain parameters, which cannot be directly measured, estimation algorithm is employed to infer the property from the data which can be directly measured. Sensors are becoming more sophisticated with built in calibration and self-diagnostic capabilities.

Sensors and Transmitters for Process Automation:
Devices such as Thermocouples, Resistance Temperature Detectors (RTDs), Pressure sensing diaphragms, strain gauges, Pitot tubes, Venturi tubes are some examples of process sensors. Sensors make direct contact with the process fluid and translate/convert the mechanical signal into electrical signal with the help of transducers, converters and transmitters.

Level transmitters, flow transmitters, valve position transmitters, temperature transmitters and pressure transmitters are commonly used in the process automation systems. A transmitter is a device that converts a reading from a sensor into a standard signal and transmits that signal to a monitor or controller. Unlike electrical sensors, these sensors and transmitters are installed at all over the plant at different locations such as pipe lines, tanks, pressure vessels, pump rooms, compressor rooms etc. It may be noted that the sensors in oil and gas plants, chemical and petrochemical plants are often installed in the hazardous area (explosion classified).

Sensors and Transmitters for Power System Automation:
Current Transformers (CT), Potential Transformers (PT) are most common type of sensors in the Power system. These sensors (CT & PT) produce electrical signals and therefore separate transmitter and transducers are not needed. Nevertheless in certain applications, temperature sensors and transmitters are used to monitor the temperature of the electrical equipment. Power system sensors are placed in the electrical equipment, which are installed at substation and power station buildings in nonhazardous area.

2.2.2 Actuators:

Control is ultimately about action affecting changes to the plant that attempt to modify its behaviour in accordance with the desired objectives. These changes are realised through actuators.

Actuators for Process Automation: Devices such as Flow control valves, ON/OFF valves, Motor Operated Valves, Pumps are the most commonly used actuators in Process control systems. Unlike in power systems, these actuators are installed all over the plant at different locations such as pipe lines, tanks, pressure vessels, pump rooms, compressor rooms etc.

Actuators for Power System Automation: Relays, circuit breakers, contactors, transformer tap changers, generator governors are commonly used actuators in the electrical system. These actuators are usually installed inside the electrical equipment, located in the substation and power station buildings.

2.2.3 Field data interface devices:

These are small computerized units deployed in the field at specific sites and locations. These devices serve as local collection points for gathering reports from sensors and communicate with central host computer. They also deliver commands to the actuators. RTUs, also known as Remote Telemetry Units, provide this interface. They are primarily used to convert electronic signals received from field interface devices into the language (known as the communication protocol) used to transmit the data over a communication channel.

Field data interface devices for Process Automation:
Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCSs) and Fieldbus systems are most common type of field data interface devices.

PLCs are usually computers connected to a set of input/output (I/O) devices. The computers are programmed to respond to inputs by sending outputs to maintain all processes at set point. Traditional PLCs include communications modules that allow PLCs to report the state of the control program to the computer plugged into the PLC or to a remote computer via a communication link.

DCSs are controllers that, in addition to performing control

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functions, provide readings of the status of the process, maintain databases and advanced man-machine-interface.

Fieldbus is an industrial network system for real-time distributed control. It is a way to connect instruments in a manufacturing plant. Fieldbus works on a network structure which typically allows daisy-chain, star, ring, branch, and tree network topologies.
Field data interface devices for Power System Automation:
Microprocessor based communicating type electrical Relays and SCS (Substation Control Systems) are field data interface devices for Electrical Automation Systems.

Electrical Relays are commonly known as IEDs (Intelligent Electronic Devices). IEDs integrated with the electrical controls and protections are called BCPUs (Bay Control and Protection Units). These IEDs and BCPUs are usually installed inside the electrical switchboards, located in the substation/power station buildings.

SCS (Substation Control Systems) are controllers that, in addition to performing control functions, provide readings of the status of the electrical network, maintain databases and advanced man-machine-interface.

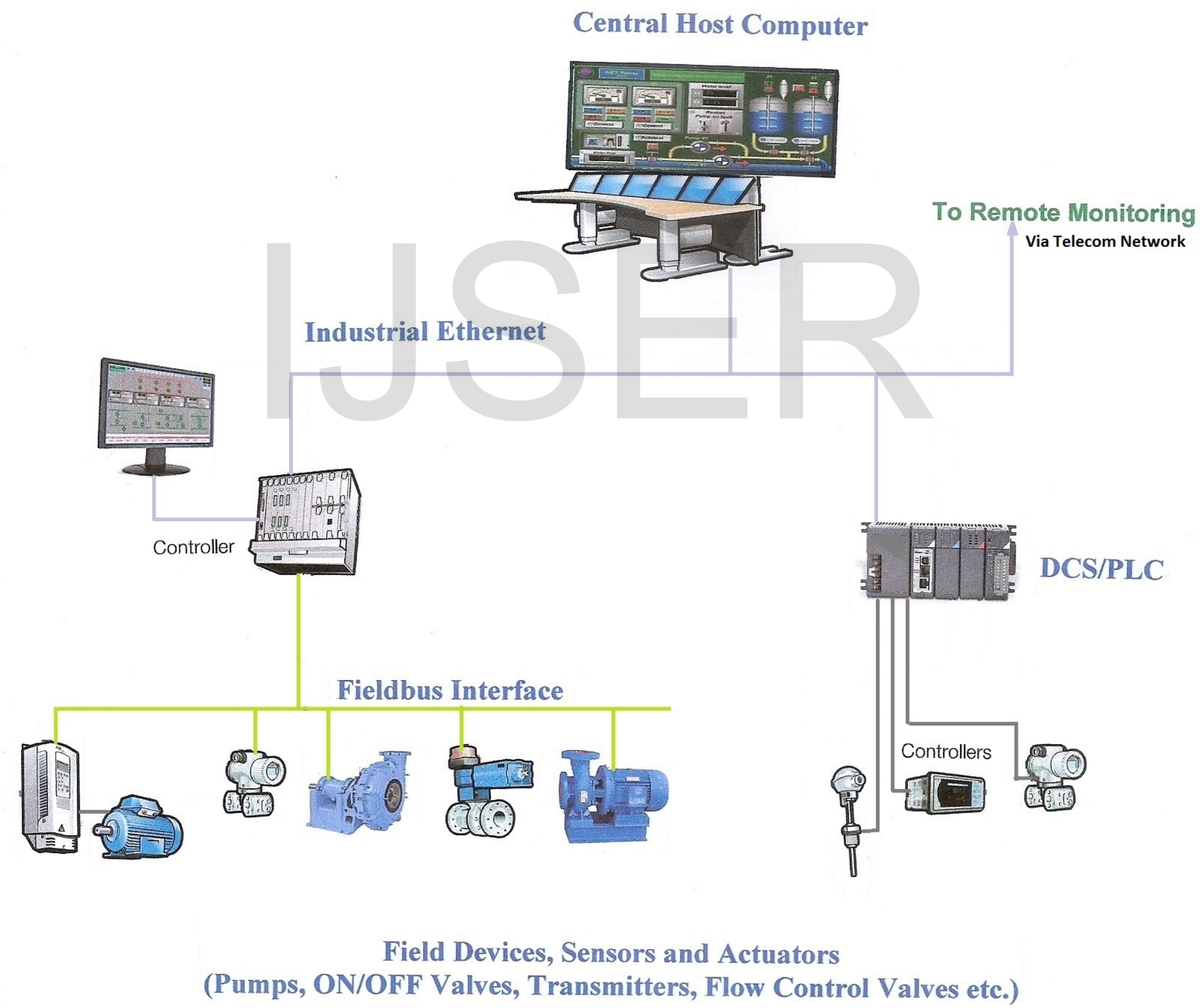

Fig-1 (Typical Architecture of Process Automation System)

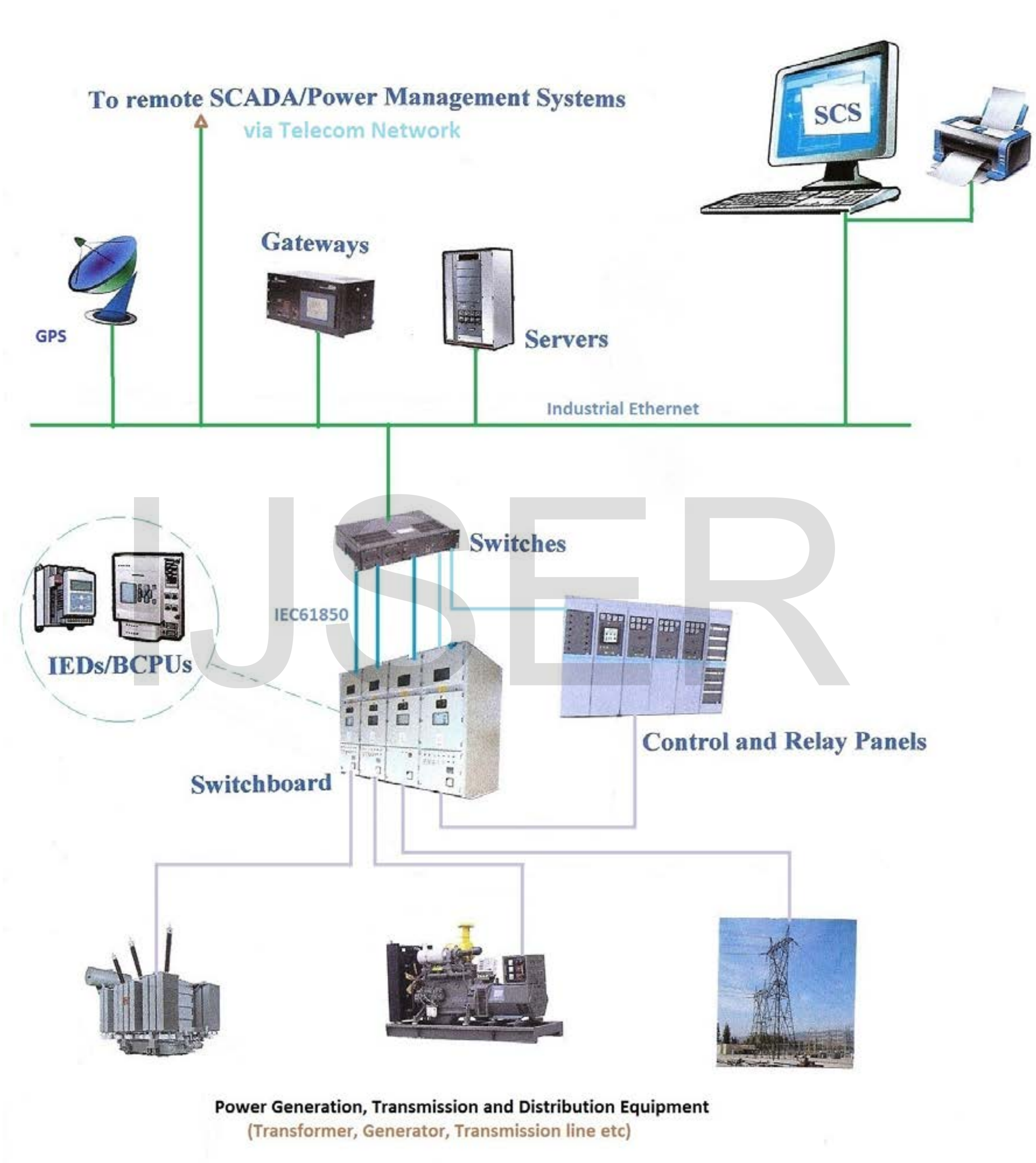

Fig-2 (Typical Architecture of Power System Automation)

2.2.4 CENTRAL HOST COMPUTER SERVER(S):

These are sometimes called a SCADA (Supervisory Control and Data Acquisition) Center, Master Station or Master Terminal Unit (MTU). These are larger computer consoles or a network of computer servers that serve as the central processor for the Automation system. Master units provide a human interface to the system and automatically regulate the managed system in response to sensor inputs. The computers process the information received from and sent to the RTU and present it to human operators in a form that the operators can understand and work with. Operator terminals are connected to the central host computer by a LAN/WAN, which makes it possible for the operator to view number of screens simultaneously.

It is possible to link the central host computer of automation systems to office-based applications such as GIS systems, hydraulic modelling software, electrical simulation software, drawing management systems, work scheduling systems, and information databases.

Central host computer server(s) for Process Automation Systems: These are commonly known as Master Terminal Units or Process SCADA systems and installed in the operator's central control facility, enables two-way data communication and control of remote field devices.

Central host computer server(s) for Power Automation Systems: These are commonly known as Power Management Systems (PMS) or Centralised SCADA system. These PMS or SCADA systems are installed in the Central Electrical Control room which is meant for monitoring and control of the entire electrical network which comprises of several generating stations, substations, transmission and distribution networks.

2.2.5 THE COMMUNICATIONS NETWORK:

Communication network connects the central host computer server(s) to the Field data interface devices. The communication backbone system can be radio, telephone, cable, satellite, etc, or any combination of these. The use of cable is usually implemented with in a plant or factory. Cables are not practical for systems covering large geographical areas because of the high cost of the cables, conduits and the extensive labour in installing them. The use of radio offers an economical solution for remote sites.

Although dedicated communication network is used for SCADA, it is possible to integrate SCADA LANs into everyday office computer networks. The advantage of this arrangement is that there is no need to invest in a separate computer network for SCADA operator terminals. In addition, there is an easy path to integrating SCADA data with existing office applications, such as spreadsheets, work management systems, data history databases, Geographic Information System (GIS) systems, and water distribution modelling systems.

2.3 Technological Developments and Achievements:

Technologies of process automation and power system automation have experienced parallel developments and achievements.

2.3.1 Technological Developments and Current Trends in Process Automation Field:

In the early days of process control, i.e. in the 1950s and before, the control system implementation consisted of analogue devices which were connected with hard wired logics.
Direct Digital Control (DDC) was implemented in the industry in 1962 to replace the analogue control system by a computer. DDC offered lower cost, improved operator interfaces, and better flexibility compared to analogue technology.
The invention of the cheaper, faster, and more reliable microcomputers paved the way to develop Microprocessor based PLCs in early 1970s.
True Distributed Control Systems (DCS) were introduced in early 1980s by larger vendors, however developing networks with support for redundancy and real-time communication was still a challenge. With the introduction of distributed control came the necessity to communicate between the devices and the controllers but there was no standard communication protocol to connect them with. Another issue was that even though the controllers were now digitalized, the controller still communicated with the devices using analogue signals. A large drive was thus towards digitalization of the communication with the devices and standardization of the communication.

PROFIBUS PA (the initial Fieldbus systems) was developed during early 1990s to replace the analogue signals. Fieldbus is an industrial network system for real-time distributed control. It is a way to connect multiple instruments like transmitters, analysers, control valves, on/off valves to RTUs, DCS and PLCs. Fieldbus works on a network structure which typically allows daisy-chain, star, ring, branch, and tree network topologies. Furthermore, the fieldbus system allows power to be delivered over the bus to the field instruments. There is no need to lay separate power and control cables. This reduces the field cable requirements.

HART (Highway Addressable Remote Transducer) protocol was published in 1993. Wireless HART technology was introduced in 2003. This technology was further enhanced in 2012. The HART Communication Protocol defines a bi-directional field communication protocol standard for instrument, control and automation systems. HART Communication offers enhanced features in the data flow between hosts and field devices. These include device re-configuration, diagnosing and troubleshooting instruments, providing additional measurements provided by the device etc. HART Communication Protocol can provide many benefits, including playing a major role in improving plant operations, increasing asset availability and reducing maintenance costs. HART technology is easy to use and very reliable. The HART Protocol provides two simultaneous communication channels on the same wire: 4-20mA "current loop" analogue and a HART digital signal. While the analogue signal continues to provide primary values to and from field instruments, the digital signal provides additional device information.

FOUNDATION fieldbus was developed during late 1990s constitutes the next level of standardisation. FOUNDATION fieldbus devices now support control schemes such as PID control on the device side instead of forcing the controller to do the processing.

Both FOUNDATION fieldbus and PROFIBUS technologies are now commonly implemented within the process control field, both for new developments and major refits whereas 4-20mA with `HART' protocol is preferred for IPF (Instrument Protective Functions) devices in today's world.

2.3.2 Technological Developments and Current Trends in Power Automation Field:

Master Stations: Prior to the development of digital computers in 1960s, analogue computers were being used to monitor and control of generation voltage, frequency, power export and import within various electrical networks. The invention of the cheaper, faster, and more reliable digital computers helped to develop Electrical SCADA in 1970s. However the early SCADA system was developed with custom made software, which was difficult to upgrade or integrate with any other system in future. Concept of open standard operating systems was initiated in1990s and later on became popular in the Electrical SCADA system to support real-time applications.

Remote Terminal Units (RTUs): Until mid 1970s, the interface among the relays and the field data interface devices used to be achieved through hard wires and extensive use of auxiliary relays and analogue transducers. Although microprocessor based RTUs were developed in mid 1970s, the actual revolution in the electrical automation came in 1980s when the microprocessors based communicating type protective relays, meters and controllers were developed. These microprocessors based communicating type protective relays, meters and controllers were named as IEDs (Intelligent Electronic Devices) and became very popular in the industries by 1990s.

IEDs used to have proprietary protocol of communication as defined by their manufacturers. Inoperability issues were observed while integrating IEDs and RTUs of different manufacturers.

In order to resolve the inoperability issues, standardization of protocol was needed and Distributed Network Protocol version 3 (DNP/3) was proposed in 1993 for inter-device communication involving SCADA RTUs, and provides for both RTU-to-IED and master-to-RTU/IED. It is based on the three-layer enhanced performance architecture (EPA) model contained in the IEC 60870- 5 standards, with some alterations to meet additional requirements of a variety of users in the electric utility industry.

Publication of IEC 61850 in 2004 offered several advantages over the previous standards. Also IEC61850 standard has been embraced by both the IEC and ANSI communities. This standard was mainly designed to provide a single protocol for a complete substation and allow for interoperability between products from different vendors. IEC61850 standard uses the innovative extensible markup language or XML-based substation configuration description language (SCL). SCL formally describes the configuration of IEDs in terms of functionality e.g. circuit breaker control, measurements and status values and reporting. A second edition of the IEC61850 standard was published in 2010 which supports dual port redundancy for IEDs.

The new generation of automation systems uses open standards such as IEC 60870-5-104, DNP 3.0 and IEC 61850 and commercial technologies, in particular Ethernet- and TCP/IP-based communication protocols.

2.4 Difference in Interface requirements of Sensors and Actuators

In the power systems, sensors and actuators are located within the periphery of a substation in a safe zone and therefore it is very easy to power them and interconnect them with the RTUs. Whereas the sensors and actuators of process control systems are distributed all around the plant. Also the sensors and actuators in oil and gas plants, chemical and petrochemical plants are often installed in the hazardous area (explosion classified). Therefore the technologies which reduce field cables and also suitable for installation in hazardous area are most suited for process automation systems to power and interconnect the sensors and actuators.

2.5 Difference in Accuracy and Response Time Requirement:

The 'accuracy' of a measurement depends on the particular duty and service. For example for a typical process plant the 'accuracy' required for flow meters and level gauges are around 5%, for regular monitoring and control purpose. However for critical applications, the accuracy requirement can be more stringent (i.e. better than 1%).

For power system, 'accuracy' of measurement of 1% is considered as adequate for sensors in normal metering.

However accuracy requirement for sensors in revenue/tariff metering is normally expected to be 0.2%. During abnormal/fault condition, the sensors of the power system are required to measure very high currents (in the order of 6-20times the normal rated current). 'Accuracy' of sensors for power system protection is expected to be better than 5%, under abnormal condition.

Typically, a default control execution time of 1 second is considered to be adequate for the central host computer of process control and power system automation application.

Certain activities such as troubleshooting and tripping analysis in power system requires very high degree of accuracy in time stamping (better than 1 millisecond)

2.6 Difference in Philosophy of Protection:

Functionalities in the central host computers, such as Human machine interface, Status Monitoring, Alarming, Historical data processing for process automation and power system automation systems are very similar.

The basic control and protection system for process equipment/system is managed by the process controllers (PLC, DCS, fieldbus controller or Central host computer) and is responsible for normal operation of the plant and typically used in the first layer of protection against unsafe conditions. If the basic process control system fails to maintain control, alarms will notify operations that human intervention is needed to re-establish control within the specified limits. If the operator is unsuccessful then other layers of protection, e.g. pressure safety valves, Emergency Shut Down System (ESD) or Safety Instrumented System need to be in place to bring the process to a safe state and mitigate any hazards. Emergency shut-down signals being safety critical, are generally hardwired to the actuators.

Typically power system equipment cannot handle the abnormal condition (fault condition) for more than of 1 second. Therefore the typical response time for power system protection should be much less than 1 seconds (typically less than 100 milliseconds). Hence all protection and protection related control function for electrical equipment (i.e., panel, generator, transformer, busbar, etc.) are configured in the IEDs and BCPUs levels (protection relays, bay control units etc) which are located local to the equipment concerned. This level is self-supporting, that means all control and protection equipment on this level are capable of supporting the primary function of this part of the network, without depending on any communication with the automation systems/SCS. In case when central host computer is required to control certain critical functions (such as load shedding, emergency shut down etc), the signals are generally hardwired to the breakers directly (and not through the communication link).

2.7 Difference in Communication Speed:

Presently, communication speed of 31.25 kilobytes/second for field bus system (FOUNDATION fieldbus H1) at field level is considered to be adequate for process automation and communication speed of 100 megabytes/second (IEC61850) at substation level is considered to be adequate for power system automation.

3. Expectations and Challenges for Future Automation System:

Future development is focusing on about how technology can lower costs, improve reliability and enhance efficiency.

Time has come to move away from expensive and less capable legacy technologies. Recently a number of Ethernet-based industrial communication systems have been established, most of them with extensions for real-time communication. These have the potential to replace the traditional fieldbuses in future.

Power system automation is gradually moving towards 100% fiber optic connection right from sensor level up to the central computer. However the same technology may not be adopted for process automation system, because of the requirement of transmitting power and control signal together in one cable.

As per ABB review special report August 2010 (see references), even though IEC 61850 standard was created by substation automation domain experts, the same standard is capable of operating in process and power generation plant automation also. Future can offer better integration of process automation with power system automation by eliminating inoperability and reducing significant hardwire and engineering effort.

Future advancement in communication technology can help both process and power system automation. Faster and reliable communication network can help delegating majority of operator's burdens to the automation system in future. 3D graphics with enhanced animation can be expected with faster and reliable communication network in future.

Due to the cyber security threat, many of the industries use dedicated communication network for automation system, although it is possible to integrate SCADA LANs into everyday office computer networks and internet. Therefore the full advantage of SCADA is not realized such as spreadsheets, work management systems, data history databases, Geographic Information System (GIS) etc. But the most reasonable response to security risk is not a policy of elimination, but rather mitigation.

In future the expected increase in use of open standards for communications and interconnectivity will make hacking and other malicious activities even easier. Future SCADA has to tackle these major security concerns.

4. Conclusions:

Difference in the nature of control variables between process and power systems have definite impact on the automation systems. Technologies currently available to us does not fully support common automation system for process and power systems in a plant due to inoperability issues. We can expect the seamless integration of both the systems and have a common automation system in future, which will result in less investment cost and better efficiency. Cyber security threat prevents utilization of automation system to its full potential. Future automation systems have to overcome many challenges but it has the potential to dramatically change the present concept of operation and maintenance of industrial plants.

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